

COVERED --- IN SMOKE

Why burning wood threatens the health of Europeans

- Dr Mike Holland



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About the Author of the Technical report

Dr Michael Holland has been involved in quantifying the impacts of air pollution from power systems since 1990, when he worked at the heart of the influential EC-US Fuel Cycles Study funded by the European Commission, EU Member States and the US Department of Energy. Following completion of the initial study in 1995 this work continued in Europe as the ExternE Study until 2005. Since 1996 Mike has provided cost-benefit analysis of air quality and industrial policies for a variety of organisations including not only the European Commission, but governments in the UK, France, Sweden, China and a number of other countries. He has also provided analysis for international organisations including the Organisation for Economic Cooperation and Development (OECD) and the World Bank.

Summary

A summary of key findings and analysis written by Fern staff based on research by Dr Mike Holland is also available at: www.fern.org/report/biomassandhealth

Key findings:

More than 1,300 deaths a year are linked to air pollution from 27 biomass burning power stations in the EU. Other health impacts include more than 20,000 cases of bronchitis, hundreds of hospital admissions for respiratory and cardiac conditions and nearly two million restricted activity days, including 240,000 lost working days across Europe.

Exposure to smoke from domestic biomass use caused 40,000 deaths across the EU28 in 2014. The authors of the study that found this (Sigsgaard et al) say it is a conservative figure. Dr Holland extends Sigsgaard's analysis to produce a fuller picture of the range of health impacts from domestic biomass burning. In a single year, he estimates that in addition to the 40,000 deaths across the EU, there were more than 130,000 cases of bronchitis, more than 20,000 respiratory and cardiac hospital admissions, a million asthma symptom days for children aged 5-19, 43 million restricted activity days and 10 million working days lost. All because of exposure to fine particles from domestic biomass emissions.

Economic costs of health impacts from domestic biomass use in the EU are estimated to be in the range of 33 billion euros to 114 billion euros a year (at 2015 price levels). This monetary assessment takes account of factors such as direct healthcare costs, lost productivity in the workplace and welfare losses from the pain, suffering and inconvenience of being unwell, in line with valuations adopted by the European Commission.

Recast of the Renewable Energy Directive likely to cause between 435 and 1,100 additional deaths each year due to increased emissions from biomass power station, depending on the renewables target adopted. Other substantial health impacts will include an additional 7,000 to 19,000 cases of bronchitis annually, 16,000 to 40,000 asthma symptom days in children, and 77,000 to 190,000 working days lost. Impacts will accumulate year on year for as long as the additional biomass capacity continues to operate.

1 Introduction

1.1 The Renewable Energy Directive (RED)

The EU promotes renewable energy technologies for several reasons, including concerns over greenhouse gas emissions and local air pollution, the cost-competitiveness of energy supplies, and security of energy supply. This promotion has driven an increase in the burning of wood as the EU encouraged use of biomass in domestic appliances as well as industrial facilities. The latter includes large power stations, some of which were originally built for coal combustion, and smaller facilities specifically designed to burn wood. An additional driver of increased burning of biomass was the economic crisis of 2008, as many people in, for example, Greece, turned to wood and other biofuels as a cheap alternative to more conventional fuels in the European energy market.^{1, 2, 3}

The Renewable Energy Directive (RED) sets a binding target of 20 per cent of final energy consumption from renewable sources by 2020, with individual Member States committing to reach their own targets, ranging from 10 per cent in Malta to 49 per cent in Sweden. The Commission's biannual progress reports show that solid biomass dominates the growth in demand for heating and cooling under RED, and also makes a small contribution to renewable electricity production.⁴ Overall, it provided approximately 45 per cent of renewable energy in the 28 EU Member States (EU28) in 2016. The National Renewable Energy Action Plans (NREAPs) suggest that biomass would provide around 38 per cent of renewable energy by 2020. As some large power stations have been converted from coal to biomass, the contribution to electricity production may have increased significantly in the last two years (the latest progress report covers the period to 2015). The commitments made for increasing the use of solid biomass by 2020 across Member States through their NREAPs are shown in Table 1 using data from the Energy Research Centre of the Netherlands (ECN).⁵

The final row of the table shows that solid biomass will contribute nearly three quarters of the renewable energy required for heating and cooling across Member States by 2020. The figure for electricity is much lower, at 12.7 per cent, reflecting the availability of other renewable options in the form of hydro (30 per cent), wind (41 per cent), solar (9 per cent) and liquid and gaseous biofuels (6 per cent).

Table 1. Solid biomass contribution to increasing renewables for electricity generation and heating and cooling (Million tonnes of oil equivalent) (Mtoe). Source: ECN.

	Electricity	Heating and cooling
2005	4.7	47.7
2010	6.6	56.6
2015	9.8	66.2
2020	13.3	81.1
Biomass as % of renewable contribution in 2020	12.7	72.6

1 European Environment Agency. Air quality in Europe — 2014 report. <https://www.eea.europa.eu/publications/air-quality-in-europe-2014#tab-data-visualisations>

2 Paraskevopoulou, D., Liakakou, E., Gerasopoulos, E., Mihalopoulos, N., 2015, Sources of atmospheric aerosol from long-term measurements (5 years) of chemical composition in Athens, Greece. *Sci. Total Environ.* 527-528C, 165–178.

3 Saffari, A., Daher, N., Samara, C., Voutsas, D., Kouras, A., Manoli, E., Karagkiozidou, O., Vlachokostas, C., Moussiopoulos, N., Shafer, M.M., Schauer, J.J., Sioutas, C., 2013, Increased Biomass Burning Due to the Economic Crisis in Greece and Its Adverse Impact on Wintertime Air Quality in Thessaloniki. *Environ. Sci. Technol.* 47, 13313–13320.

4 Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Renewable Energy Progress Report, 2017, <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52017DC0057&qid=1488449105433&from=EN>

5 ECN, 2011, Renewable Energy Projections as Published in the National Renewable Energy Action Plans of the European Member States, https://www.ecn.nl/docs/library/report/2010/e10069_summary.pdf.

Alternative estimates are available from the European Environment Agency.⁶ They get almost identical results for biomass demand from electricity (13.5 vs 13.3 Mtoe) and heating and cooling (80.9 vs 81.1 Mtoe).

1.2 Revision of the Renewable Energy Directive (REDII)

The EU is currently considering a revised Renewable Energy Directive (hereafter: REDII) for the period post 2020, following the 2016 publication of the European Commission legislative proposal.^{7,8} The current proposal includes a target of a share for renewable energy of at least 27 per cent by 2030, a position supported by the Council through its Common Approach reached on 18 December 2017. The Parliament has called for a higher target, of at least 30 per cent. The Parliament will vote in early 2018 on REDII, with a possibility that they will vote to increase the target to 35 per cent. New policies are needed to supplement those already in place given that projections indicate a 24 per cent share for renewables by the target date. The Commission's proposal includes options that are designed to strengthen the sustainability framework for bioenergy, and specifically for forest biomass.

Table 2 shows the development of demand for all energy and renewable energy in the electricity, heating and cooling and transport sectors over the period from 2020 to 2030 according to Commission projections.

The decline in demand for heating results from increased energy efficiency standards, though demand for renewable heating holds largely steady. For transport there is also likely to be some improvement via energy efficiency. Whilst overall energy demand for transport is shown to decline in the table, there is some increase in provision of renewable energy to the sector. The biggest increase in renewable energy demand, however, and the only sector to show an increase in total energy demand, is electricity, with an additional 40 Mtoe required between 2020 and 2030 to meet projected demand under the Commission's energy modelling scenario "EUCO27".

Table 2. Evolution of gross final energy consumption (totals, and for renewables) by sector. Units: Mtoe. Source: European Commission REDII proposal.

	REF 2016			EUCO27			EUCO27 - REF
	2020	2030	Difference	2020	2030	Difference	2030
Gross final energy consumption – Electricity	289	302	13	290	302	12	-0.4
From renewables	103	128	25	103	143	40	15
Gross final energy consumption - Heating and cooling	540	485	-55	541	454	-87	-31
From renewables	123	124	1	124	128	4	4
Gross final energy consumption – Transport	287	274	-13	287	256	-31	-18
From renewables	32	39	7	32	46	14	7

⁶ European Environment Agency (2017) EEA Report No 3/2017, Renewable energy in Europe 2017: Recent growth and knock-on effects. <https://www.eea.europa.eu/publications/renewable-energy-in-europe-2017>.

⁷ Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast) https://ec.europa.eu/energy/sites/ener/files/documents/1_en_act_part1_v7_1.pdf

⁸ Commission Staff Working Document SWD(2016)418 Accompanying the document Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast) <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD:2016:0418:FIN>

With respect to additional demand under REDII, recognising that there will likely continue to be an increase in renewables from 2020 to 2030 under current legislation, and based on data from the Commission's proposal, it is estimated that an additional 20 Mtoe (for a 27 per cent target) and 50 Mtoe (for 30 per cent) would be required, above the forecast 24.3 per cent projection (Table 3).

Table 3. Gap between current forecast for renewables and forecast usage. Source: calculated from data presented by European Commission REDII proposal.

	Percentage	Mtoe	Gap, Mtoe
Total demand in 2030 under EUCO27		1012	
Renewables in baseline	24.30	245.916	
Renewables in policy scenario 1	27	273.24	20.324
Renewables in policy scenario 2	30	303.6	50.684

There are no specific Commission targets for biomass or other technologies. This is because such targets could distort the market which would reduce the potential for industry to meet the requirements of REDII at the lowest cost. It would also interfere with the principle of subsidiarity, which leaves Member States the freedom to develop their own plans for compliance within the broad framework defined by the overall target for renewable energy, via NREAPs⁹ and in the future the National Energy and Climate Plans (NECPs).

1.3 Objectives of this report

Combustion of biomass increases exposure to pollutants that are recognised as harmful to health. They encompass carcinogenic substances, such as wood dust and benzo(a)pyrene, substances damaging the respiratory and cardiovascular systems, most notably fine particles and nitrogen oxides (NO_x). Both short-term and long-term effects on human health arise. The negative impacts of biomass-derived pollutants have been noted in numerous studies in developing countries. The health impacts of biomass combustion in developed countries have, however, been less extensively covered though a recent study by Sigsgaard et al. estimated that the current contribution of biomass smoke from the domestic sector to premature mortality in Europe is at least 40,000 deaths per year.¹⁰

This report has been written to create a better understanding of the health impacts of these pollutants, and current policies promoting the use of solid biomass, particularly wood, as a contribution to the debate on the legislative package 'Clean Energy for all Europeans'¹¹ and REDII.

⁹ <http://iet.jrc.ec.europa.eu/remea/national-renewable-energy-action-plans-nreaps>

¹⁰ Sigsgaard, T., Forsberg, B., Maesano, I.A. et al., Health impacts of anthropogenic biomass burning in the developed world, *European Respiratory Journal* 2015; DOI: 10.1183/13993003.01865-2014, <http://erj.ersjournals.com/content/early/2015/09/24/13993003.01865-2014>.

¹¹ European Commission (2016) Commission proposes new rules for consumer centred clean energy transition. <http://ec.europa.eu/energy/en/news/commission-proposes-new-rules-consumer-centred-clean-energy-transition>.

2 Impacts

Biomass combustion has a number of impacts. Whilst this report is primarily focused on the health effects of air pollutants released from burning wood, it is also worth considering impacts on climate.

2.1 Climate

Many consider use of biomass as a fuel to be carbon neutral, as the carbon released to the atmosphere when the material is burned is already present in the biosphere and will be taken up by vegetation within a reasonable space of time, if sustainable growing practices are followed.

However, a recent European Academies Science Advisory Council (EASAC) report¹² concludes that the carbon neutrality concept is highly simplistic for several reasons:

- The inherent lower energy density of biomass relative to fossil fuels.
- Intensification of forest management associated with land use change or harvest of old-growth forests, leading to a loss of carbon storage in living trees and forest soils or decreasing carbon sinks.
- Post-harvest use of materials, the manufacture of durable commodities and construction stores carbon over long periods, while energy production causes immediate carbon release.
- Carbon emitted to the atmosphere contributes to climate change, as it is not instantly taken up by growing plants.¹³ Given slow rates of growth, it may be many decades before forests compensate for the carbon released from wood burning.

The European Commission Joint Research Centre (JRC)¹⁴ finds that for slow growing trees, the use of stem-wood for bioenergy can generate an increase in carbon dioxide (CO₂) emissions compared to fossil fuels over several decades, if all the carbon pools and their development with time are considered. Comparison of the Greenhouse Gas (GHG) balance for the use of forest materials versus coal and natural gas has concluded that the time to reach parity ranged from approximately 10 years with increased use of forest residues, to 100s of years with an increased rate of thinning, to more than 500 years when felling was increased to supply bioenergy for certain types of forest.¹⁵ The comparison with gas naturally leads to longer time-scales given that it generates less GHG emissions than coal.

The EASAC report also addresses the complexity of the forest-climate relationship beyond direct impacts of forest management through the biophysical effects of albedo, forest structure, evapo-transpiration, and the release of volatile organic compounds and microbes from plant surfaces capable of forming aerosols and subsequently clouds. EASAC refers to Ellison et al.¹⁶ who suggested that forests should be managed to increase their contribution to climate cooling through hydrological mechanisms and not just from a carbon-centric (i.e. use of biomass as a fuel) perspective. EASAC also found that “*evidence suggests that ignoring biophysical interactions – as is currently the case in the Kyoto Protocol and the Paris Agreement – could result in mitigation projects that provide little climate benefit or, in the worst case, are counterproductive*”.

12 European Academies Science Advisory Council (2017) Multi-functionality and sustainability in the European Union's forests, http://www.easac.eu/fileadmin/PDF_s/reports_statements/Forests/EASAC_Forests_web_complete.pdf.

13 Back, J. and Norton, M. Science-based forest policies urgently needed for effective management, <http://www.euractiv.com/section/climate-environment/opinion/science-based-forest-policies-urgently-needed-for-effective-climate-action/>

14 JRC (2014). European Commission, Joint Research Centre. Carbon accounting of forest bioenergy. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC70663/eur25354en_online.pdf

15 Nabuurs G-J, et al. (2017). European forests shown no carbon debt, only a long parity effect. *Forest Policy and Economics* 75, 120–125

16 Ellison D. et al. (2017). Trees, forests and water: cool insights for a hot world. *Global Environmental Change* 43, 51–61.

Further to this, the argument of carbon neutrality overlooks emissions from:

- Forest management
 - Planting
 - Production and application of fertiliser
 - Harvesting
 - Other general management activities
- Processing material so that it is fit for combustion
- Transport

With respect to transport, it is generally assumed that wood and other forest materials such as bark will be used within a short distance of the growing site and that long-range transport is uneconomic. However, this is not necessarily the case. As shown later in this report, large users of biomass can find it economically attractive to source material on global markets, leading to significant levels of emission not only from transport on land, but also from shipping.

2.2 Air pollution

The promotion of any combustion technology runs counter to efforts to improve air quality. Biomass burning is recognised as a significant source of fine particles ($PM_{2.5}$) and polyaromatic hydrocarbons,¹⁷ and is also associated with emissions of oxides of nitrogen and various other pollutants linked to the substances present in the wood.¹⁸ Some of these pollutants can react in the atmosphere to form further pollutants, including ‘secondary particles’ (such as ammonium nitrate) and ozone, which are also damaging to health. Much of the text in this section deals not with the specific contribution of emissions from biomass burning: however, it is important to understand the ‘big picture’ to put increased emissions from biomass use in context.

2.2.1 Impacts

The World Health Organisation’s (WHO) 2013 HRAPIE (Health Response to Air Pollution in Europe) study identified several health impacts of $PM_{2.5}$, NO_2 and O_3 for which evidence of causality and the exposure-response relationship were considered sufficiently robust that quantification should be undertaken to inform the development of EU policy¹⁹ (Table 4).

17 Polyaromatic hydrocarbons (PAHs) are often expressed in terms of benzo(a)pyrene (BaP), widely accepted as a marker for exposure to PAHs more generally.

18 EIONET Review: Air Quality in Europe. https://forum.eionet.europa.eu/nrc-air-quality/library/products-eionet-review/air-quality-europe-2016-report/air-quality-europe_eionet-review/download/en/1/Air%20Quality%20in%20Europe_Eionet%20review.docx

19 WHO (2013) Health Response to Air Pollution in Europe (HRAPIE) http://www.euro.who.int/_data/assets/pdf_file/0006/238956/Health_risks_air_pollution_HRAPIE_project.pdf?ua=1

Table 4. Effects of PM_{2.5}, O₃ and NO₂ for which WHO-Europe considers evidence sufficiently robust that effects should be quantified for EU impact assessments

Effect	Age group	PM _{2.5}	O ₃	NO ₂
Mortality	Adults	x	x	x
Mortality	Infants	x		
Respiratory hospital admissions	All ages PM _{2.5} , NO ₂ , >65 O ₃	x	x	x
Cardiovascular hospital admissions	All ages PM _{2.5} , NO ₂ , >65 O ₃	x	x	
Chronic bronchitis	Adults	x		
Acute bronchitis	Children	x		x
Restricted activity days	All ages	x	x	
Asthma symptom days	5-19 years	x		
Work loss days	Working age	x		

The effects shown in Table 4 are not a complete overview of the impacts of current exposure to air pollution in Europe, being restricted to those effects for which experts consulted by WHO-Europe considered sufficient evidence was available in 2013 to enable quantification. They are biased to effects of PM_{2.5} because this pollutant has been more extensively studied than other air pollutants, though in the current context, the demonstration of significant impacts linked to PM_{2.5} is important given its emission from biomass. A report from the Royal Colleges of Physicians (RCP) and of Paediatrics and Child Health in the UK²⁰ identified a further series of impacts for which there is some (if not yet definitive) evidence of effect, including:

- Low birth weight
- Stroke
- Diabetes
- Obesity
- Dementia

This additional list highlights that air pollution is damaging to health from conception to old age. It may also be linked with diseases that have increased in prevalence in recent years and are becoming a substantial burden on Europe's health care systems (e.g. diabetes, obesity and dementia).

The RCP report also found that the impacts of poor air quality will most affect those who are disadvantaged because they:

- Live in deprived areas, which often have higher levels of air pollution
- Live, learn or work near busy roads
- Are more vulnerable because of their age or existing medical conditions

²⁰ Royal College of Physicians and Royal College of Paediatrics and Child Health (2016) Every breath we take: the lifelong impact of air pollution. <https://www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution>.

2.2.2 Exposure routes linked to biomass used for combustion

Exposure to air pollution arises throughout the wood fuel chain (Figure 1).

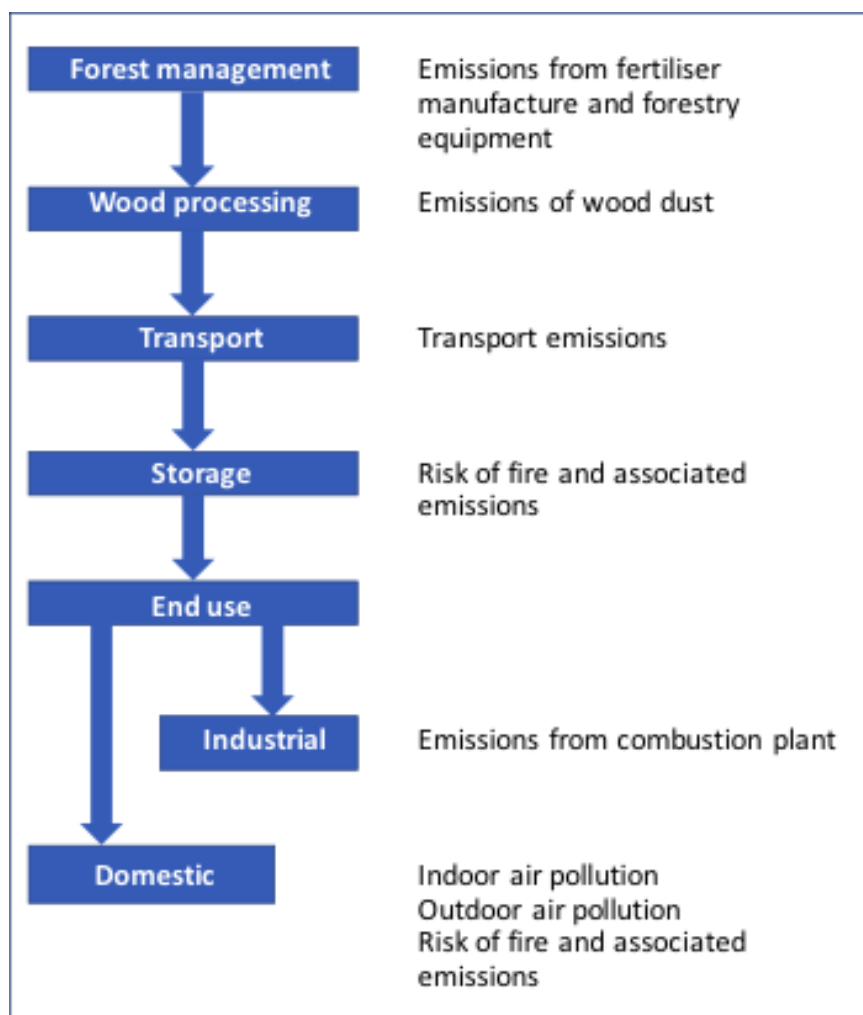


Figure 1. Exposure to air pollutants from the biomass fuel chain.

There are several exposure routes in addition to the effects identified above which generate increased levels of outdoor air pollution:

- Occupational exposures to wood dust during processing. Wood dust is recognised by the International Agency for Research on Cancer (IARC) as a Group 1 substance (carcinogenic for humans) causing cancers of the nasal cavity, paranasal sinuses and nasopharynx.²¹
- Exposure to emissions from uncontrolled fires occurring during storage. Whilst such incidents should be rare, they do occur, with several fires affecting supplies to the power stations in recent years.^{22 23 24}
- Indoor air pollution, from domestic use of biomass, especially in older stoves that are not enclosed. Exposure will arise not only during use, but also during ash removal.

There is also the risk of accidents with manual labour involving heavy machinery and heavy goods.

²¹ Wood dust. International Agency for Research on Cancer (IARC), <http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C-15.pdf>

²² The Journal (2011) Firefighters battle huge biomass fire at Port of Tyne, <http://www.thejournal.co.uk/news/north-east-news/firefighters-battle-huge-biomass-fire-4422494>

²³ BBC (2013) Port of Tyne fire: Tower blaze 'under control', <http://www.bbc.co.uk/news/uk-england-tyne-24498774>.

²⁴ <http://www.biofuelwatch.org.uk/2014/ironbridge-blaze/>

2.2.3 Legislation on air quality

There are two broad strands of air quality legislation:

- Controlling emissions
- Setting ambient concentration limits

Whilst there is a tendency to refer to non-GHG pollutants as ‘local pollutants’, they cause impacts over extended distances. At the extreme they are considered as hemispheric pollutants. EU action to control emissions was originally (1980s) focused on the continental scale, rather than the local, addressing acidification of ecosystems particularly forests and lakes. In the years since, new information has emerged that has increased attention on health impacts, again at the continental scale. Fortunately, what is good for health so far as air quality is concerned is also beneficial for ecosystems.

There are two broad strands of air quality legislation, the setting of ambient concentration limits and direct controls on emissions:

Ambient concentration limits

These are designed to ensure that individuals and ecosystems close to emission sources are not exposed to high concentrations of pollution. Where limits are exceeded, additional measures beyond those contained in the emission control legislation are required. Different types of action will be required depending on the emission sources that cause limit values to be exceeded, for example:

- Industry: Require facilities to go beyond Best Available Techniques (BAT)
- Domestic: Ban polluting fuels, require improvement of stoves
- Transport: Upgrade vehicles, ban or charge more polluting vehicles from sensitive areas, encourage people to switch away from car use to walking, cycling, or the use of public transport.

Direct controls on emissions

Emissions can be controlled in various ways, several of which overlap with climate policies:

- The use of end of pipe abatement technologies such as particle filters, or selected catalytic reduction for NO_x control (often leading to a slight increase in GHG emissions)
- The substitution of more polluting fuels with less polluting fuels (beneficial for the climate)
- Improvement of fuel quality (generally positive for the climate)
- Moving away from polluting activities (e.g. by cycling to work instead of driving a car)
- Improved product design, leading for example to improved efficiency of energy use (beneficial for the climate)
- Setting National Emission Ceilings providing a flexible mechanism for Member States to meet emission reduction targets. This opens the way for the use of economic instruments at a national or sub-national level, develop less polluting energy strategies (particularly through a move away from coal), etc. (beneficial for the climate).

Research has failed to identify population-level thresholds for exposure to ‘local’ air pollutants. With respect to fine particles, a critical study on this issue was carried out in Canada, following government concern that the use of exposure-response functions derived from studies in the USA could be misleading in Canada, where pollution levels are generally lower.²⁵ However, the new analysis supported the US conclusions even for areas where PM_{2.5} levels were just a few µg.m⁻³, levels that are below those in most of the EU. Impacts will still, therefore, arise even where legislation on emission standards and ambient concentrations is respected.

²⁵ Crouse, D. et al. (2012) Risk of non-accidental and cardiovascular mortality in relation to long-term exposure to low concentrations of fine particulate matter: A Canadian national-level cohort study. *Environ Health Perspect.* 2012 May;120(5):708-14. doi: 10.1289/ehp.1104049.

2.2.4 Compliance gap on air quality legislation

The European Environment Agency reports that there is a ‘compliance gap’ on air pollution at present, with respect to both the reduction of emissions and the meeting of ambient limit values.

- With respect to emissions, eleven Member States exceeded the National Emissions Ceiling (NEC) Directive for one or more pollutants in 2015: Austria, Belgium, Denmark, Finland, France, Germany, Hungary, Ireland, Luxembourg, Spain and Sweden.²⁶
- Projected emissions reported by 23 Member States show that 18 do not consider themselves on track towards meeting their reduction commitments set for 2020 for NO_x, NH₃, NMVOCs, SO₂ and/or PM_{2.5} on the basis of the policies and measures they currently have in place. Similarly, 22 Member States are not on track to meet one or more of their 2030 commitments.²⁶
- In 2014, 16 per cent of the EU-28 urban population was exposed to PM₁₀ levels above the EU daily limit value with 8 per cent exposed to PM_{2.5} levels above the EU target value. However, when compared to the stricter WHO Air Quality Guideline values set to protect human health, approximately 50 per cent and 85 per cent of city dwellers were exposed to PM₁₀ and PM_{2.5} concentrations exceeding the WHO’s recommendations.²⁷
- In 2014, 7 per cent of the urban population in the EU-28 were exposed to NO₂ concentrations above the identical WHO and EU standards.²⁷
- 20 and 88 per cent of the EU population were exposed to levels of Benzo[a]pyrene (BaP) above (respectively) the EU limit and the WHO guidelines in 2014.²⁸

The difficulty in meeting limit values is highlighted by the fact that there is still non-compliance despite the limits entering into force as long ago as 2005 for PM₁₀, 2010 for NO₂ and 2012 for BaP. Adding to existing emission levels in any sector will clearly make this job harder.

Monitoring and analysis has found that the contribution of residential wood combustion to PM₁₀ and PM_{2.5} concentrations during the winter range from <5 to up to 40 per cent depending on location. The highest winter contributions are reported in the Alpine Valleys, the Po Valley, Oslo, Zurich, and rural areas in Austria and Germany.¹⁸ Several studies carried out in urban areas (e.g., Vienna, Berlin, Zurich) report that the particles from residential combustion originate mainly at the regional scale, and that only a minor proportion is emitted locally. This demonstrates that the problem is not specific to the immediate vicinity of biomass burning, but is significantly more widespread.¹⁸ Several problems are identified for improving the performance of biomass burning in the home, relating to the long life-time of stoves, variable quality of fuels and inadequate maintenance of equipment. These factors all lead to an increase in emissions from biomass beyond optimal performance.

2.2.5 Residual health impacts of air pollutants in Europe

Further to this, even if legislation were to be complied with, substantial impacts on health would remain. Analysis to support the Commission’s impact assessment for the revision of the Thematic Strategy on Air Pollution in 2013 estimated total impacts for series of scenarios.²⁹ Table 5 shows results for the MTFR (Maximum Technically Feasible Reduction) scenario for 2030, representing the highest level of control considered in the study (the final policy recommendation gives higher figures still). Even when all measures are applied and all legislation complied with, significant impacts remain, recognising the non-threshold nature of the relationship with the pollutants of concern. The list is not complete:

26 European Environment Agency (2017) Air pollution in Europe: Countries struggle to meet emission limits due to emissions from agriculture and transport. <https://www.eea.europa.eu/highlights/air-pollution-in-europe-countries>.

27 European Environment Agency (2016) Stronger measures needed to tackle harm from air pollution. <https://www.eea.europa.eu/highlights/stronger-measures-needed>.

28 European Environment Agency. Air quality in Europe — 2016 report. https://www.eea.europa.eu/publications/air-quality-in-europe-2016/at_download/file

29 Holland, M. (2014) Cost-benefit Analysis of Final Policy Scenarios for the EU Clean Air Package, Version 2, Corresponding to IIASA TSAP Report 11, Version 2a, <http://ec.europa.eu/environment/air/pdf/TSAP%20CBA.pdf>.

additional effects of particulate matter and ozone, and additional impacts associated with other pollutants (NO₂ etc.) could be added to the list.

The table does not take specific account of other pollutants associated with wood burning, such as BaP, which is carcinogenic, and for which domestic solid fuel use (particularly wood) is the major source in the EU.

Table 5. Annual impacts to health and economic equivalents for the EU28 under the Maximum Technically Feasible Reductions (MTFR) scenario for 2030. Source: Holland, 2014.

		Cases, days, events	Cost, € million
Mortality, as life years lost	O ₃	14,000	830
Respiratory hospital admissions	O ₃	17,000	38
Cardiovascular hospital admissions	O ₃	73,000	160
Minor restricted activity days	O ₃	70,000,000	2,900
Mortality, as life years lost	PM _{2.5}	1,800,000	105,000
Mortality, as deaths	PM _{2.5}	220,000	480,000
Infant mortality, deaths	PM _{2.5}	280	460
Chronic bronchitis (adults)	PM _{2.5}	170,000	9,000
Bronchitis (children)	PM _{2.5}	530,000	310
Respiratory hospital admissions	PM _{2.5}	72,000	160
Cardiovascular hospital admissions	PM _{2.5}	55,000	120
Restricted activity days	PM _{2.5}	230,000,000	21,000
Asthma symptom days	PM _{2.5}	5,600,000	230
Lost working days	PM _{2.5}	55,000,000	7,100
Monetary total			150,000-530,000

Note: the range is based on alternative metrics for mortality (lower bound based on life years lost valued using value of a life year, upper bound based on deaths valued using value of statistical life).

2.3 The REDII proposal and air pollution

Part 4 of the Commission's Impact Assessment on REDII ³⁰ notes that:

With regards to air pollution, the increased use of solid biomass for heating in urban areas is a key driver; combined with the fact that most of the existing stock of domestic boilers and stoves is inefficient and polluting. Ecodesign requirements will improve the situation, but the replacement of the existing stock will take time given the lifetime of such devices. More generally, the scale and location of biomass combustion also strongly influences its impacts on air pollution.

The reference to location recognises that the use of biomass for domestic heating could be especially problematic, given the low height of release of pollutants, and proximity to housing. It is noted that pressure on local authority budgets is leading to a reduction in the availability of staff able to ensure that local regulations on solid fuel burning are complied with.

The Commission's impact assessment on its REDII proposal contains no quantification or otherwise substantive detail of air quality impacts,³¹ but provides the following text:

³⁰ http://eur-lex.europa.eu/resource.html?uri=cellar:1bdc63bd-b7e9-11e6-9e3c-01aa75ed71a1.0001.01/DOC_4&format=DOC

³¹ European Commission (2016) Commission Staff Working Document Impact Assessment accompanying the document Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast). <http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1490879548464&uri=CELEX:52016SC0418>.

Requirements for air pollution

1. *As described in the problem definition, air pollution is addressed through a number of legal measures at EU level. These include Directive 2004/107/EC aimed to reduce concentrations of pollutants in ambient air; Directive 2008/50/EC on ambient air quality, as well as the Large Combustion Plants Directive (2001/80/EC).*
2. *Air pollution specifically related to biomass is particularly linked to the stock of old boilers used in particular in households, as well as by the scale of use in certain populated areas. Replacing the stock of existing boilers could be incentivised through e.g. scrappage schemes but this goes beyond the scope of this impact assessment.*
3. *Regarding large combustion plants, specific standards are set for air emissions in the context of the Directive on large combustion plants.*
4. *Given the fact that air pollution from biomass is specifically addressed through other EU measures and regulations, it is not considered appropriate to set specific requirements in the context of this policy initiative.*

Paragraph 2 recognises the difficulty of ensuring rapid progress in emission controls on the domestic sector, and the problems that arise when biomass facilities are located in more densely populated areas. This reflects the concern raised in Section 2.2.4 regarding non-compliance with current legislation. Increased use of biomass is likely to widen this compliance gap for emissions of fine particles, BaP, and NO_x particularly to the extent that it competes against other renewables or natural gas.

Paragraphs 1 and 3 correctly recognise the presence of other EU legislation on air quality, whilst paragraph 4 regards this other legislation on emissions as being sufficient to control the problem. However, the presence of legislation on air pollution does not mean that emissions are harmless to health or the wider environment (see Table 5, showing the residual impacts of air pollution in Europe, after all legislation and additional technical measures beyond currently agreed legislation are fully in place).

The following statement (or words to this effect) is made more than once in the impact assessment:
Emissions of greenhouse gas emissions and local air quality pollutants could be higher under this scenario, especially if the renewable energy was displaced by fossil fuels.

This may be true for biomass if it displaces coal or oil, but given questions raised above, it does not apply to displacement of natural gas so far as ‘local air quality pollutants’ are concerned, and possibly also GHGs. For the purpose of considering how renewable capacity can reduce GHG emissions, the appropriate comparison is not with fossil fuels, but with other renewables.

In conclusion, the air pollution impacts of biomass are therefore of material importance to REDII and should have been considered in the impact assessment.

3 Health effects of biomass pollution from domestic sources in the EU28

3.1 Future demand for biomass for heating

To provide aggregated estimates of impacts associated with the targets for 2030 proposed by the European Commission (27 per cent) and the European Parliament (30 per cent) it is necessary to develop some illustrative scenarios of demand for biomass (specifically, in contrast to renewables more generally) for heating and cooling.

It is first necessary to consider information on future trends in demand as presented in the Commission's Impact Assessment.³¹ Figure 2 shows that it is anticipated under their EUCO27 scenario³² that there will be no increase in capacity for residential heating and cooling. The figure shows reduced energy use in the sector in the period 2020 to 2030 because of action on energy efficiency, increased electrification, and reduced use of coal and oil. Biomass use increases from 2015 to 2020, but declines gradually afterwards. Distributed heat (which will contain some biomass input) is reasonably constant over the period from 2015 to 2030.³³ The impact assessment contains no information on future developments of industrial biomass demand up to 2030.

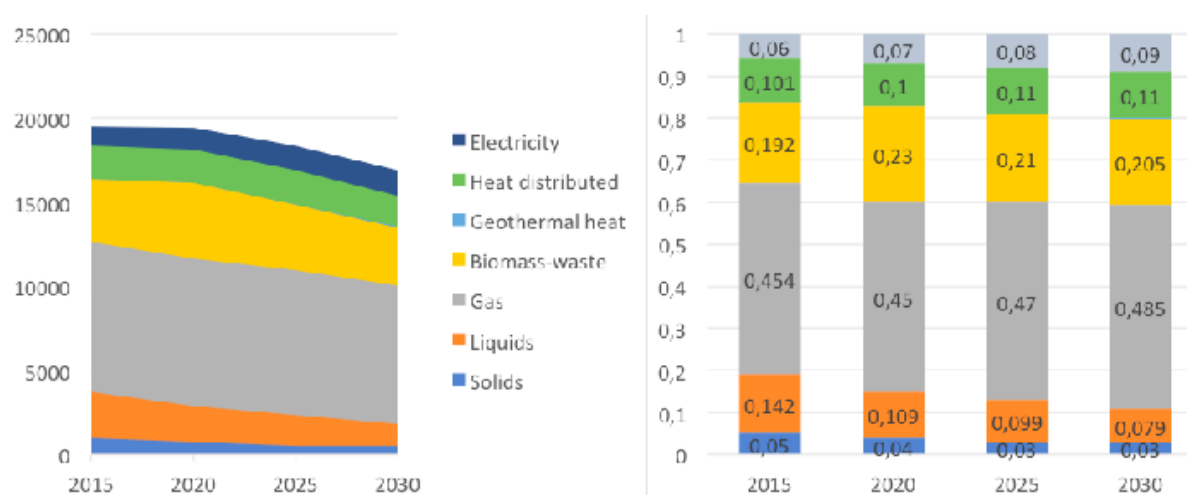


Figure 2. Final energy by energy consumption (kilotonnes of oil equivalent (ktoe)) in residential heating and cooling – EUCO27 scenario. Source: PRIMES Model, as shown in the EU Impact Assessment on REDII.³¹ Renewable municipal waste has been included in solid biomass.

On this basis, increased capacity for biomass appears unlikely in the domestic sector, though there is some possibility that the use of natural gas, in particular, could be partially displaced, perhaps through expansion of district heating systems.

From the perspective of the current report, therefore it is relevant to consider the external costs of continued use of biomass in the domestic sector at current levels.

32 EUCO27 is the central policy scenario adopted by the Commission, also used for the Impact Assessments supporting the proposal for a revision of the Energy Efficiency Directive, for the proposal on the Effort Sharing Regulation, and the Staff Working Document on low-emission mobility, which are in line with 2030 minimum ambition levels as stated by Heads of States and Governments in October 2014.

33 Given the greater efficiency of cogeneration of electricity and heat compared to electricity alone, the lack of growth for distributed heat looks surprising, particularly when considering actions in the waste sector that encourage cogeneration for incineration plant. However, it is possible that the lack of change in the amount of distributed heat shown in the figure masks a move away from coal fired cogeneration to cogeneration with biomass and waste.

3.2 Emissions

The latest report from the European Environment Agency (EEA) recognises residential combustion as an important source of air pollution, referencing emissions of both fine particles and polycyclic aromatic hydrocarbons (PAHs).^{28,34} The EEA notes that for the domestic sector, the use of coal and oil has declined in many countries in recent years, demand for gas has remained steady, but demand for biomass increased after 2005.²⁸ The ‘commercial, institutional and household’ sector accounted for 57 per cent of emissions of fine particles ($PM_{2.5}$) (Figure 3) and 75 per cent of BaP emissions in 2105³⁴ (Figure 4) (BaP being commonly used to indicate overall PAH emissions).

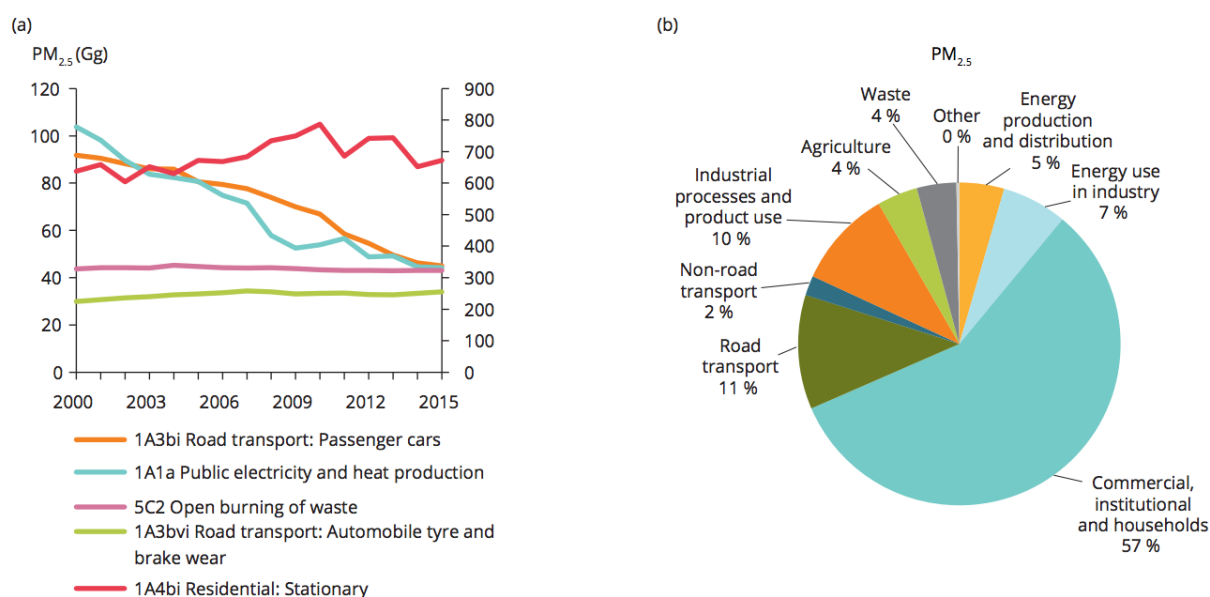


Figure 3. $PM_{2.5}$ emissions in the EU-28: (a) trend in emissions from the five most important key categories, 1990-2015; (b) share by sector group, 2015; Source: EEA.³⁴

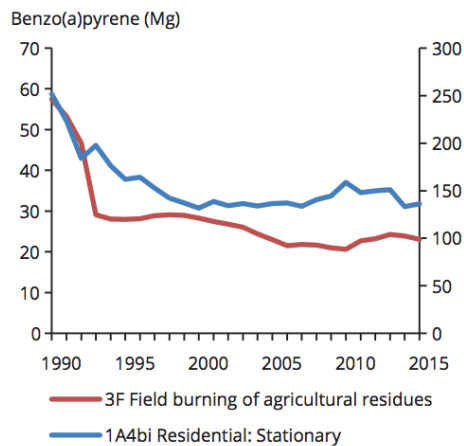
Data reported by the WHO indicate that biomass emissions of $PM_{2.5}$ from residential combustion account for approximately 33 per cent of total EU emissions,³⁵ while data from the Netherlands Organisation for Applied Scientific Research (TNO) indicate that over 40 per cent of BaP emissions are from residential biomass burning.³⁶

34 European Environment Agency (2017) European Union emission inventory report 1990–2015 under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP). <https://www.eea.europa.eu/publications/annual-eu-emissions-inventory-report>.

35 World Health Organization (2015) Residential heating with wood and coal: Health impacts and policy options in Europe and North America. http://www.euro.who.int/_data/assets/pdf_file/0009/271836/ResidentialHeatingWoodCoalHealthImpacts.pdf.

36 TNO (2011) European Emission Inventory of four indicator PAHs for 2005. Presented at Dioxin 2011, Brussels, Belgium. http://macc.copernicus-atmosphere.eu/about/project_structure/input_data/d_fire/lit/European%20Emission%20Inventory%20of%20four%20indicator%20PAHs%20for%202005.pdf.

(a)



(b)

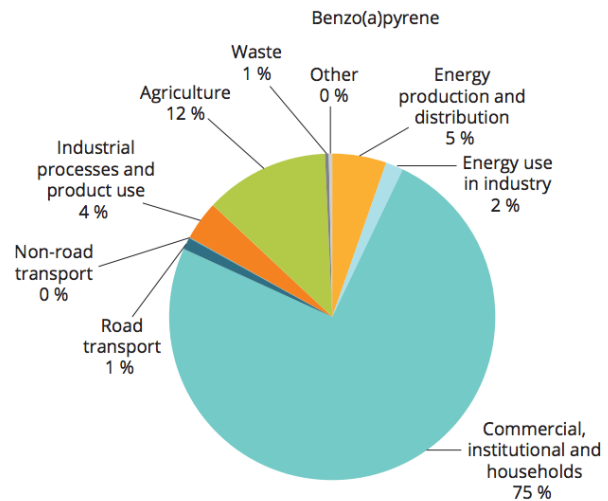


Figure 4. B(a)P emissions in the EU-28: (a) trend in emissions from the two most important key categories, 1990-2015; (b) share by sector group, 2015; Source: EEA.34

Figure 5 provides a projection from the International Institute for Applied Systems Analysis (IIASA) showing that whilst $PM_{2.5}$ emissions from domestic biomass have increased in recent years, they are projected to decline slowly in future years, through improved energy efficiency, installation of better appliances and other means. Other sources decline more rapidly over the full period.

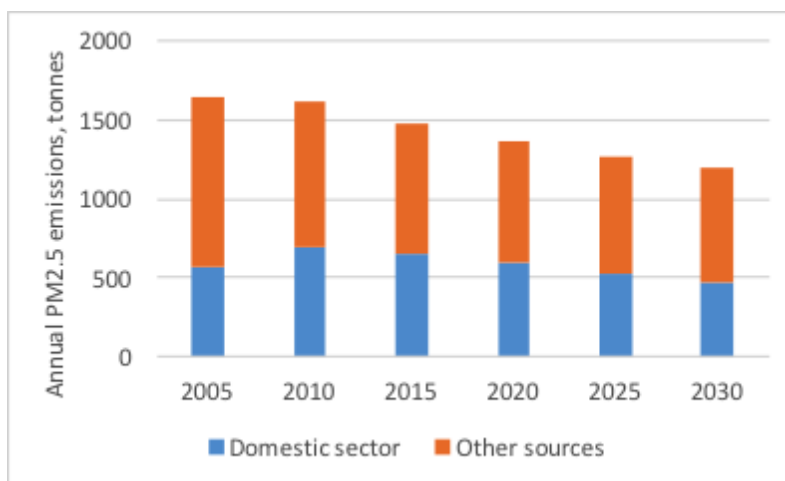


Figure 5. Trend in emissions of $PM_{2.5}$ from the domestic sector relative to other sources for the EU28. Source: IIASA (2014).37

37 IIASA, 2014, The Final Policy Scenarios of the EU Clean Air Package, TSAP Report #11 version 1.1a, http://www.iiasa.ac.at/web/home/research/researchPrograms/air/policy/TSAP_11-finalv1-1a.pdf.

3.3 Exposure to particles from domestic wood burning

The EEA notes that impacts on air quality from residential burning are most notable in rural areas, with the highest contributions of around 40 per cent occurring in the Alpine valleys, the Po Valley, Oslo and rural areas in Austria and Germany. Analysis of urban air, however, finds a lower contribution from residential burning. Of this contribution, much is linked to long-range transport of pollutants from more rural locations. As noted above, this demonstrates that ‘local’ air pollutants are more mobile in the environment than the name suggests, and can affect a wide area.

Sigsgaard et al¹⁰ estimates 40,000 deaths in the EU28 occurred in 2014 from exposure to smoke from biomass (mainly wood) burning associated with domestic combustion. This estimate was made by combining the lower bound of a range of 10 to 30 per cent of population exposure to particles being attributable to biomass burning, with the 400,000 deaths estimated to be associated annually with exposure to fine particles by the European Environment Agency.³⁸ The rationale for selecting a 10 per cent estimate for European particulate matter exposure is provided in the Supplementary Material provided with the paper, based on data collated from 14 European studies published between 2006 and 2014 (reproduced in Table 6, with data rearranged to separate out PM_{2.5} and PM₁₀ and different seasons).

The studies used for the dataset collected particles in the different regions and characterised the contribution of wood smoke by reference to chemical tracers. Data show that wood smoke makes a variable contribution to total primary particle levels. The share is higher in the winter than for the whole year, in line with intra-annual variability in demand for heating. There is only one annual PM_{2.5} sample, from Helsinki, indicating a 17 per cent contribution from wood smoke. For PM₁₀ there are five annual samples ranging from 6 to 11 per cent. All annual data cover urban sites. For samples covering the ‘cold’/autumn/winter periods the contribution to PM_{2.5} varies from 10 to 49 per cent, and for PM₁₀ varies from 8 to 59 per cent. The higher values are linked to locations that seem to have been chosen because of a high level of wood burning in the area and so are not widely typical. There are some biases affecting the data:

- The fraction of PM_{2.5} linked to domestic combustion is higher than the fraction of PM₁₀.³⁹
- They do not account for the contribution of wood burning to the formation of secondary organic and inorganic aerosols following release of precursor pollutants. (bias to underestimation)
- They assume that all wood burning is domestic. Given long-range transport of fine particles there will be some contribution from non-domestic combustion also.

Taking all factors into account it concludes with an estimate that wood smoke in Europe contributes an average of 10 per cent to particle exposures. This was the figure adopted by Sigsgaard et al. The figure is clearly not precise. Bearing in mind the uncertainties that affect it, a range of +/- 50 per cent seems reasonable.

38 European Environment Agency. Air quality in Europe — 2014 report. Luxembourg, European Environment Agency, 2014. <https://www.eea.europa.eu/publications/air-quality-in-europe-2014>

39 European Environment Agency (2011) <https://www.eea.europa.eu/data-and-maps/indicators/emissions-of-primary-particles-and-5/assessment-3>.

Table 6. Data collated by Sigsgaard et al for contribution of biomass (chiefly wood) smoke to outdoor Particulate Matter levels in Europe, rearranged to distinguish PM_{2.5} from PM₁₀ and annual data from information covering shorter periods. Entries in bold highlight annual mean estimates.

Location	Urban?	Poll.	Low	Mid	High	Period
Helsinki	Urban	PM_{2.5}		17%		Annual
Helsinki	Urban	PM _{2.5}	18%	24%	29%	‘Cold’
Helsinki	Suburban	PM _{2.5}	31%	49%	66%	‘Cold’
Duisburg	Urban	PM _{2.5}		13%		Autumn
Amsterdam	Urban	PM _{2.5}		11%		Winter
Grundsomagle	Rural	PM _{2.5}		25%		Winter
London	Urban	PM _{2.5}		12%		Winter
Prague	Urban	PM _{2.5}		37%		Winter
Tanumshede	Rural	PM _{2.5}		25%		Winter
Vindinge	Rural	PM _{2.5}		10%		Winter
Flanders	7 sites	PM₁₀	5%	9%	13%	Annual
Graz	Urban	PM₁₀	9%	11%	13%	Annual
London	Urban	PM₁₀		6%		Annual
Salzburg	Urban	PM₁₀	7%	10%	12%	Annual
Vienna	Urban	PM₁₀	5%	6%	7%	Annual
Flanders	7 sites	PM ₁₀	9%	16%	22%	Winter
Lombardy	Rural	PM ₁₀	11%	18%	24%	Winter
Lombardy	Urban	PM ₁₀	5%	10%	15%	Winter
London	Urban	PM ₁₀		8%		Winter
Northern Sweden	Rural	PM ₁₀		36%		Winter
Southern Germany	Rural	PM ₁₀		59%		Winter
Susa	Rural	PM ₁₀	20%	38%	55%	Winter
Torino	Urban	PM ₁₀	9%	14%	19%	Winter

3.4 Quantification of impacts linked to domestic biomass use for 2014

As noted above, Sigsgaard's analysis provides an estimate of 40,000 equivalent attributable deaths from domestic biomass burning in the EU28 annually.

The analysis can be extended to include effects on morbidity using results from analysis completed to support the European Commission's 2013 revision of the Thematic Strategy on Air Pollution.⁴⁰ These results cover hospital admissions, bronchitis, days of restricted activity and days with asthma symptoms, and their monetary equivalents. Total economic damage, in line with the valuations adopted by the European Commission is €33 to 114 billion annually (2015 price levels).

Table 7. Mortality and morbidity effects associated with exposure to fine particles emitted from biomass combustion, 2014, combining results from Sigsgaard et al. (2015) and Holland (2014)

	Impact units	Impact	Value, €million
Chronic Mortality *	Life years lost	353,503	24,500
Chronic Mortality *	Premature deaths	40,000	106,000
Infant Mortality (0-1yr)	Premature deaths	57	110
Chronic Bronchitis, adults	Cases	31,568	2,030
Bronchitis in children aged 6 to 12	Cases	101,113	71
Respiratory Hospital Admissions	Cases	13,683	36
Cardiac Hospital Admissions	Cases	10,499	28
Restricted Activity Days	Days	43,068,185	4,800
Asthma symptom days (children 5-19yr)	Days	1,066,408	54
Lost working days	Days	10,674,603	1,700
Total monetary value			33,000-114,000

* The estimates of chronic mortality in terms of life years lost and deaths are alternative measures of the same effect and cannot be added.

Given the list of possible effects cited by the RCP,²⁰ it is possible that even this omits important effects on morbidity, noting particularly the links made with dementia, obesity and diabetes.

Monetary valuation seeks to account for several factors:

- Healthcare costs
- Lost productivity in the workplace
- Welfare losses in terms of the personal costs from pain and suffering, inconvenience, etc. of being unwell.

The latter group of costs are typically derived using population surveys, designed to elicit the individuals' 'willingness to pay' not to suffer the disease concerned. The methods followed are broadly similar to those used to derive disability adjusted life years (DALYs) and quality adjusted life years (QALYs) in health economics, developing an understanding of human preferences. The valuation approach used by the European Commission is conservative. Adoption of the value of a statistical life (VSL, used to value deaths) recommended by OECD of €3 million⁴¹ would increase the upper bound of the range shown to €127 billion annually. It is not the purpose of this paper to argue for the adoption of one valuation over another: it is simply noted that the estimates of impact and their monetary equivalent linked to biomass burning in the EU28 are substantial.

⁴⁰ Holland, M., Cost-benefit Analysis of Final Policy Scenarios for the EU Clean Air Package Version 2, Corresponding to IASA TSAP Report#11, Version 2a, October 2014, <http://ec.europa.eu/environment/air/pdf/TSAP%20CBA.pdf>.

⁴¹ <http://www.oecd.org/environment/mortalityriskvaluationinenvironmenthealthandtransportpolicies.htm>

The estimate of 40,000 deaths annually is described by Sigsgaard et al. as ‘conservative’, indicating a likelihood that the true figure is higher. Several factors need to be considered when assessing whether the figure really is conservative or not:

- Particle emissions from the domestic sector account for approximately 40 per cent of the total emission of PM_{2.5} in the EU28 (Figure 5). Sigsgaard et al. cite a lower fraction of total PM emissions from domestic wood stoves of 25 per cent. Accepting that the higher figure includes all domestic emissions (hence coal burning as well as wood), the figure of 25 per cent appears credible.
- A meta-analysis and review by Belis and colleagues regarding the contribution of different sources to total PM, based on 272 records, concluded that around 15 per cent of PM exposure in Europe could be attributed to biomass burning. The attribution to biomass as a source was based on receptor models which rely on the concentrations of specific PM components (namely levoglucosan, together with organic carbon and elementary carbon ratios) from which the fraction originating from biomass burning is estimated.
- The often quoted estimate of 400,000 deaths from air pollution from a report by the EEA will include effects of other types of particle, including secondary aerosols formed in the atmosphere.

Accepting that there will be some uncertainty around the 40,000 estimate, it is a reasonable figure on which to base conclusions, alongside the estimates of other health impacts shown in Table 7. Annual impacts are estimated to be valued at between €27 and 50 billion annually.

4 Industrial use of biomass for heat and power: case studies on individual plant

4.1 Initial review of plant burning biomass

The ideal design of a plant for burning woody biomass might have the following characteristics:

- High efficiency
- Supplying both heat and power
- Strong control of emissions to air and other media
- Located close to wood or other biomass feedstock

As the following text will demonstrate, performance against these characteristics is questionable. Some plants meet the criteria, many others do not (or will not when built).

As part of the current work, data has been collected from over 100 operating or proposed biomass plants in Europe. The review sought to identify the following data for as many plants burning biomass, particularly wood, as possible:

- Location of plant
- Operating company
- Electrical output capacity
- Heat output capacity
- Energy input
- Fuels used
- Load factor
- Efficiency
- Emissions of NO_x, SO₂, PM
- Emissions of GHG
- Emissions of trace pollutants (organics, metals, etc.)

Data were collected from a number of different sources, including:

- Enipedia (http://enipedia.tudelft.nl/wiki/Main_Page)
- The European-Pollutant Release and Transfer Register (E-PRTR)
- Company reports and websites
- Planning applications
- A database of planned and operational biomass plant in the UK (<http://www.biofuelwatch.org.uk/wp-content/maps/uk-biomass.html>)

There are numerous data gaps in the database, with particular problems with the availability of emissions data. Planning applications tend to discuss emission limits rather than annual emissions, leaving open the question of the extent to which the plant will use the regulated limit to the full, operating hours and other factors. Whilst emission limits provide a basis for assessing likely peak contributions to ground level concentrations, there is significant uncertainty associated with their use for the quantification of damage to public health. For the largest plant considered here, emissions of particles, SO₂ and NO_x are available from the E-PRTR. However, the emissions of some or all pollutants from smaller plants are often below reporting thresholds. Recognising the many factors that can influence emissions, the methods below are based to the extent possible on emissions data from actual plants rather than estimates that may be somewhat hypothetical.

The results of the survey demonstrate substantial variation between facilities (Table 8) with respect to the characteristics considered. An appreciation of this variation is also important to understand the wider consequences of incentivising the use of biomass as a fuel.

Table 8. Variation in the characteristics of plant designed to generate electricity and/or heat from biomass.

Output	Heat only, electricity only, or both (combined heat and power, CHP)
Size	Around 10 thermal megawatts (MWth) to several thermal gigawatts (GWth)
Fuel	Biomass only, or biomass with coal, lignite, municipal and other wastes
Type of biomass	Waste wood, wood chips, wood pellets, logs, straw and other agricultural materials, energy crops (e.g. miscanthus, willow coppice)
Source of biomass	Local, through to international with some plant sourcing biomass outside Europe (e.g. the southern US states)
Quantity of biomass required	From tens of thousands of tonnes to several million tonnes of woody material annually
Plant efficiency	30 to 90 per cent
Load factor	25 to 90 per cent

It was apparent from the review that a number of very large coal fired plant have been converted to burn biomass either on its own or co-fired with coal or other fuels. Given the very different scale of some of these facilities, the case study treats plants that have been designed originally to burn coal separately from plants originally designed to burn biomass.

Table 9 provides an overview of the facilities identified during the review, by country.

Table 9. Overview of biomass facilities identified here, by country

	Number	Typical output	Size range	Typical fuel
Austria	8	CHP	1-16 MWe, 12-37 MWth	Waste wood
Belgium	4	Electricity	80-546 MWth	Coal and biomass
Hungary	2	Electricity (+heat?)	100 MWe	Biomass
Netherlands	3	Electricity only, and CHP	200-600 MWe	Coal and biomass
Finland	6	CHP	125-265 MWe, 100-400 MWth	Wood, wood wastes
Latvia	1	CHP	23 MWe, 45 MWth	Wood chips
France	1	Electricity	170 MWe	Wood chips
Denmark	5	CHP	35-793 MWe, 77-918 MWth	Various fuels
Poland	8	Electricity only, and CHP	205-2,820 MWe, 266-1,561 MWth	Coal and biomass
Lithuania	2	CHP	11-20 MWe, 40-50 MWth	Biomass
Sweden	14	Heat only, and CHP	4-389 MWe, 11-1,755 MWth	Wood , other biomass
UK	52	Electricity, a few CHP	15-2,000 MWe	Biomass only, coal and biomass

The very large number of facilities identified in the UK is based on a listing provided by Biofuelwatch.⁴² This includes 19 plants that are operating, 32 in planning or construction and one that has since shut down. The types of application being made in the UK provide an illustration of response to legislation that promotes ‘renewable’ energy technologies in a relatively open market. It is very likely that not all of those that are currently in the planning system, including some that have been approved, will be built, and that some of those that are currently operational, particularly plants that have been converted from coal burning, have closed or are in the process of closing. However, the largest plant, Drax, with an

⁴² <http://www.biofuelwatch.org.uk/2015/uk-bioenergy-maps/>, <http://www.biofuelwatch.org.uk/wp-content/maps/uk-biomass.html>

electrical capacity of two GW from biomass is operating successfully and will continue to operate for the foreseeable future. Few of the UK plants have any heat capacity attached. Drax accounts for 2 GW, the other UK plants (operational and planned combined), add up to 3.5 GW. Scaling up usage at Drax to other facilities in the UK (operating and planned) indicates that, should all be built, there will be demand for 18 million tonnes of wood annually. A higher figure, of 35 million tonnes annually, can be calculated from the figures in the Biofuelwatch survey, which are in turn based on figures provided in applications to develop new, or upgrade existing, plants. The large additional demand for woody material from Drax indicates the potential for a small number of very large facilities to distort the market that smaller plants operate in which may have further consequences, for example on the extent to which additional capacity is in the form of combined heat and power (CHP) involving higher efficiencies.

4.2 Methods

A total of 26 plants were identified for which some usable emissions data were available (9 old coal plants, and 17 purpose built biomass facilities). These are considered for the plant by plant case studies.

For the facilities that were originally coal fired, emissions data are available from the E-PRTR for NO_x, PM₁₀ and SO₂ in most cases. Some data are missing for the two Belgian plants in the list, Rodenhuize and Langerlo. These have been set to the E-PRTR reporting thresholds for SO₂ (150 tonnes/year) and PM₁₀ (50 tonnes/year).⁴³ These figures appear low compared to average emissions per unit capacity for other plants in the list.

For the 17 facilities designed specifically to burn biomass, NO_x data are available from E-PRTR in all cases, but only eight plants have SO₂ data and only one has PM data. SO₂ data are available for the larger plant, but not the smaller. Missing data have been estimated by multiplying the NO_x emission by the ratio of the upper BAT limits for PM and SO₂ relative to those for NO_x.

The monetised value of health damage is estimated from emissions data using the approach followed by the EEA in assessing impacts associated with facilities reporting to the E-PRTR:⁴⁴

- Emissions are multiplied by estimates of damage per tonne emission for NO_x, SO₂ and PM₁₀. These estimates were derived using the same methods, models, functions and valuation data as are used for the impact and benefits assessment of EU air quality policies. Given that the present study is concerned only with health impacts, the original calculations used for the EEA have been re-analysed to take out non-health impacts (to crops and materials).
- Sectoral adjustments are applied to adjust from national average damage to figures more representative of damage linked to emissions from industrial facilities. This is performed using factors of:
 - 0.78 for NO_x
 - 0.87 for SO₂
 - 0.5 for PM
- Valuations are uplifted by a factor of 1.201, in line with the HICP (Harmonised Index of Consumer Prices) inflation rate from 2005 to 2017 to provide estimates in current prices.

As an additional step, health impacts (life years lost, deaths, hospital admissions, etc.) are back-calculated from the economic damage by accounting for the valuation data, response functions and other parameters used in the original calculations that underpin the EEA damage per tonne estimates.

Results are expressed as damage per year, and then aggregated damage over 30 years. Future values are uplifted at an average rate of 1.6 per cent per year to reflect increased incomes, using projections of Gross Domestic Product/capita from the OECD. They are also discounted back to 2017 using the 4 per

⁴³ http://prtr.ec.europa.eu/docs/Summary_pollutant.pdf

⁴⁴ <https://www.eea.europa.eu/publications/costs-of-air-pollution-2008-2012>, see Annex 2 of that report for damage per tonne values

cent discount rate used in analysis for the European Commission. Combining the two gives an overall adjusted discount rate of 2.4 per cent.

4.3 Case studies on plants originally designed to burn coal

A number of power stations originally designed to burn coal and other fossil fuels have in recent years been converted to burn biomass either on its own or in combination with other fuels such as coal or municipal waste, with varying degrees of success: some of these plant continue to burn biomass, others, such as Ensted in Denmark have closed down. Plants for which E-PRTR provides some emissions data are shown in Table 10. Annual damage estimates for these plants are shown in Table 11.

Table 10. Details of plants converted from coal use to burn biomass or biomass and coal. Emission units: tonnes. Includes only plants for which some emissions data were available.

		MWe	MWh	Fuel	NO _x	PM ₁₀	SO ₂
Rodenhuize	Belgium	205		Coal / biomass	709	50	150
Langerlo	Belgium	400		Coal / biomass	1,210	50	582
Kozienice	Poland	2,820	266	Coal / biomass	16,100	752	31,000
Łagisza	Poland	1,060		Coal / biomass	3,960	84	3,630
Ostrołęka	Poland	740	456	Coal / biomass	4,220	83	5,630
Żerań	Poland	350	1,561	Coal / biomass	3,100	287	6,890
Poznań Karolin	Poland	276		Coal / biomass	2,060	106	1,810
Wrocław	Poland	263		Coal / biomass	1,560	53	2,670
Kielce	Poland	11	300	Coal / biomass	304	107	565
Totals		6,125	2,583		33,223	1,572	52,927

Note: red font denotes emissions data that are not included by E-PRTR, for which reporting thresholds have been adopted.

Table 11. Annual damage for plants burning biomass or biomass and coal that have been converted from coal use.

		NO _x , €M	PM, €M	SO ₂ , €M	Total, €M
Rodenhuize	Belgium	2.76	1.12	3.54	7.42
Langerlo	Belgium	4.71	1.12	13.74	19.56
Kozienice	Poland	77.39	12.37	382.28	472.04
Łagisza	Poland	19.03	1.38	44.76	65.18
Ostrołęka	Poland	20.28	1.37	69.43	91.08
Żerań Heat	Poland	14.90	4.72	84.96	104.59
Poznań Karolin	Poland	9.90	1.74	22.32	33.97
Wrocław	Poland	7.50	0.87	32.93	41.30
Kielce	Poland	1.46	1.76	6.97	10.19
Totals		158	26	661	845
Average damage per Megawatt of electrical output (MWe)		25,800	4,300	108,000	138,000

The final row of the table normalises damage against MWe, ‘MW electrical output’, without accounting for useful heat output.⁴⁵ The reason for not including heat output here is that scenarios the Commission

⁴⁵ http://www.externe.info/externe_d7/?q=node/45, page 83 and following text and analysis.

investigated for REDII demonstrate that future demand for heat should decline over time, largely as a consequence of the energy efficiency measures that the EU has and is continuing to introduce, with demand for heating from biomass (Table 2) and use of distributed heat (Figure 2) remaining static. The potential market for additional renewable heat technologies is likely to be limited as a result. The same does not apply to electricity, for which a significant increase in renewable provision is forecast over the period 2020-2030.

Table 12. Annual health impacts across the plant burning biomass or biomass and coal that have been converted from coal use.

	Total incidence	Incidence/MWe	€/MWe
Mortality, life years lost	10,895	1.78	102,737
Mortality, deaths	989	0.16	358,620
Infant Mortality, deaths	4.9	0.00079	1,295
Chronic Bronchitis, adult cases	832	0.14	8,151
Bronchitis in children	16,286	2.66	1,564
Respiratory, cardiac hospital admissions	513	0.084	198
Restricted Activity Days	1,268,301	207.09	20,087
Asthma symptom days in children	36,841	6.02	253
Lost working days	176,092	28.75	3,738
Total cost low			138,021
Total cost high			393,905

Results show that nearly 1,000 deaths annually are associated with the operation of the 9 plants considered, with numerous other health impacts affecting short- and long-term disease. Results are dominated by SO₂, though a significant part of this will be linked to continued use of coal at the power stations considered.

The decision to invest in a facility is a commitment to continue operation for a long period of time. Assuming a plant lifetime of 30 years generates the following impacts (with future economic values discounted at an adjusted rate, accounting for future income growth, of 2.4 per cent).

Table 13. 30 year plant lifetime health impacts across the facilities burning biomass or biomass and coal that have been converted from coal use.

	Total incidence	Incidence/MWe	€/MWe
Mortality, life years lost	326,863	53	2,231,563
Mortality, deaths	29,681	4.85	7,789,657
Infant Mortality, deaths	146	0.0238	28,127
Chronic Bronchitis, adult cases	24,959	4.08	177,040
Bronchitis in children	488,577	80	33,963
Respiratory, cardiac hospital admissions	15,383	2.51	4,299
Restricted Activity Days	38,049,019	6,213	436,322
Asthma symptom days in children	1,105,221	180	5,488
Lost working days	5,282,748	863	81,189
Total cost low			2,997,991
Total cost high			8,556,085

4.4 Case studies on plant originally designed to burn wood

The adaptation of existing fossil fuel plants to burn biomass may be limited to a small number of facilities, although some, as shown above, will be very large. Analysis has also considered 17 plants for which some emissions data are available in the E-PRTR. Characteristics of these facilities are described in Table 14. It is notable that many of these plants are significantly smaller than those considered above, and emissions are also lower, especially for SO₂.

Table 14. Details of plants burning biomass that have not been converted from coal use. Emission units: tonnes. Includes only plants for which some emissions data were available.

		MWe	MWh	Fuel	NO _x	PM ₁₀	SO ₂
Simmering	Austria	16	37	Waste wood chips	115	4	41
Awirs	Belgium	80		Biomass, HFO, RFO, natural gas	187	7	67
Alholmens	Finland	265	160	Paper and sawmill residues	663	60	436
Kymijärvi II	Finland	160	320	Solid recovered fuel	1,140	41	658
Vaasa	Finland	140	170	Wood (mainly forest residue)	1,280	46	308
Kaukaan Voima	Finland	125	110	Wood and peat	368	13	182
Seinäjoki	Finland	125	100	Woodchips, peat and coal	416	15	555
Ajka	Hungary	102		Biomass	609	22	359
Jelgava	Latvia	23	45	Wood chips	171	6	62
Fortum Klaipėda	Lithuania	20	50	Biomass, waste	252	9	91
Šiauliai	Lithuania	11	40	Wood chips, peat, natural gas	108	4	39
Brista	Sweden	42	108	Wood chips	186	7	67
Hässelbyverket	Sweden	75	200	Wood pellets	122	4	44
Värtaverket	Sweden	389	1,755	Mixture of coal and wood	425	15	202
Blackburn Meadow	UK	30		Wood	243	9	87
Chilton Biomass	UK	18		Waste wood	148	5	103
Wilton	UK	33		Sawmill residues	108	4	39
Totals		1,654	3,095		6,541	272	3,340

Note: red font denotes emissions data that have been extrapolated using the ratio of upper BAT limit PM₁₀ and SO₂ emissions vs upper BAT limit NO_x emissions

Table 15 uses the methods developed by the EEA to analyse facilities reporting to the E-PRTR.⁴³ This generates the damage estimates per plant, and per MWe.

These results can be converted back to their component health effects (taking account of valuations, response functions, affected fraction of the population, etc.) with results shown in Table 16.

Table 15. Annual damage for plants burning biomass that have not been converted from coal use.

		NOx, €M	PM, €M	SO ₂ , €M	Total, €M
Simmering	Austria	0.94	0.06	0.85	1.85
Awirs	Belgium	0.73	0.15	1.59	2.47
Alholmens	Finland	0.92	0.14	1.88	2.93
Kymijarvi II	Finland	1.58	0.10	2.83	4.51
Vaasa	Finland	1.78	0.11	1.32	3.21
Kaukaan Voima	Finland	0.51	0.03	0.78	1.32
Seinajoki	Finland	0.58	0.03	2.39	3.00
Ajka	Hungary	4.28	0.33	4.43	9.04
Jelgava	Latvia	0.48	0.03	0.56	1.08
Fortum Klaipėda	Lithuania	0.89	0.06	0.96	1.91
Šiauliai	Lithuania	0.38	0.02	0.41	0.82
Brista	Sweden	0.38	0.02	0.36	0.77
Hässelbyverket	Sweden	0.25	0.01	0.24	0.50
Värtaverket	Sweden	0.87	0.05	1.10	2.02
Blackburn Meadows	UK	0.81	0.13	1.32	2.26
Chilton Biomass	UK	0.49	0.08	1.55	2.13
Wilton	UK	0.36	0.06	0.59	1.00
Totals		16	1.4	23	41
Average damage per MWe		9,800	850	14,000	24,700

Table 16. Annual health impacts across the plants burning biomass that have not been converted from coal use.

	Total incidence	Incidence/MWe	€/MWe
Mortality, life years lost	526	0.318	18,371
Mortality, deaths	48	0.029	64,127
Infant Mortality, deaths	0.2	0.00014	232
Chronic Bronchitis, adult cases	40	0.024	1,457
Bronchitis in children	786	0.475	280
Respiratory, cardiac hospital admissions	25	0.015	35
Restricted Activity Days	61,233	37.030	3,592
Asthma symptom days in children	1,779	1.076	45
Lost working days	8,502	5.141	668
Total cost low			24,680
Total cost high			70,437

The decision to build a biomass combustion plant will clearly have consequences for an extended period of time, reflecting the operating lifetime of the facility. Table 17 shows results for an assumed 30 year plant lifetime. Data on additional incidence of effects from Table 16 is simply multiplied by a factor 30 to derive these estimates, whilst economic values are expressed as Net Present Value, discounted at an adjusted rate of 2.6 per cent (the 4 per cent typically used by the European Commission, net of increased willingness to pay to prevent effects associated with growing incomes).

Table 17. 30 year plant lifetime health impacts across the facilities burning biomass that have not been converted from coal use.

	Total incidence	Incidence/MWe	€/MWe
Mortality, life years lost	15,781	10	399,040
Mortality, deaths	1,433	0.87	1,392,917
Infant Mortality, deaths	7	0.0042	5,030
Chronic Bronchitis, adult cases	1,205	0.73	31,658
Bronchitis in children	23,588	14	6,073
Respiratory, cardiac hospital admissions	743	0.45	769
Restricted Activity Days	1,837,004	1,111	78,021
Asthma symptom days in children	53,360	32	981
Lost working days	255,051	154	14,518
Total cost low			536,089
Total cost high			1,529,967

4.5 Comparison of plants originally designed to burn biomass with plants originally designed to burn coal

For this comparison it is not appropriate to compare the results per MWe of Table 11 with those from Table 15, given that plants are located in different countries and hence have different damage/tonne pollutant estimates applied. It is instead assumed that all plants are located in the same country (Germany was used, but the conclusions drawn are not sensitive to the country selected). Results are shown in Table 18. Damage associated with ‘ex-coal’ plants is about a factor three greater than damage with plants developed originally to burn biomass. Part of this difference may be linked to continued use of coal, which is reflected in the higher SO₂ emissions of the ‘ex-coal’ plant. However, the ‘ex-coal’ plants also have higher emissions of both NO_x and PM per unit of capacity.

Table 18. Comparison of economic costs of health impacts from ‘old coal’ biomass with dedicated biomass plants per unit of electrical capacity (MWe). For the purpose of comparison, it is assumed that plant are located in Germany and results are aggregated to provide net present value over 30 years.

	€/MWe ex coal	€/MWe biomass
Mortality (low, based on valuation of life years lost)	3,404,209	1,104,318
Mortality (high, based on valuation of deaths)	11,882,983	3,854,815
Infant Mortality	42,908	13,919
Chronic Bronchitis in adults	270,072	87,611
Mortality (low, based on valuation of life years lost)	51,810	16,807
Respiratory, cardiac hospital admissions	6,558	2,127
Restricted Activity Days	665,601	215,920
Asthma symptom days in children	8,371	2,716
Lost working days	123,852	40,177
Total cost low	4,573,381	1,483,595
Total cost high	13,052,155	4,234,091

5 Estimating the health impacts of using biomass to meet the proposed REDII targets

5.1 Progress in developing new renewable capacity

To determine how much additional biomass capacity will be needed to meet the 27 and 30 per cent targets, it is first necessary to assess current plans and capacity by technology. Table 19 provides data from the EEA's 2017 survey of renewable energy in Europe, focusing on the delivery of the NREAPs to 2020.

Table 19. Renewable electricity in the EU28⁶

Technology	Final energy ktoe			
	2005	2014	Est 2015	NREAP 2020
Hydropower excluding pumped storage	29,682	29,966	29,858	31,786
Onshore wind (normalised)	5,670	18,889	20,843	30,303
Solid biomass including renewable MSW	4,756	8,971	9,469	13,460
Solar photovoltaic	126	7,941	8,669	7,062
Biogas	1,102	4,967	5,096	5,493
Offshore wind (normalised)	273	2,750	3,784	11,740
Geothermal	464	535	544	943
Concentrated solar power	-	469	469	1,633
Bio-liquids (compliant)	-	406	466	1,096
Tidal, wave and ocean energy	41	42	41	559
Total renewable energy	42,114	74,937	79,238	104,075

Progress for the different technologies can be summarised as follows:

- Hydropower: there has been no significant increase in capacity since 2005, and there is only a modest increase foreseen by 2020 in the original NREAPs. It is assumed that even if this is met, a further increase in capacity of hydropower is unlikely.
- Onshore wind: capacity has more than trebled since 2005, though significant future growth is needed to reach the 2020 target.
- Offshore wind: capacity has increased by a factor of 10 since 2005, but by 2015 the total capacity was still only about a third of that forecast in the NREAPs for 2020. The technology is, however, developing and there are a number of active projects of high capacity underway.
- Solid biomass: biomass capacity has almost doubled since 2005, though remains some way short of the NREAP target according to data from 2014 and the estimates for 2015. However, in some countries, such as the UK, there is strong interest in biomass. A survey in the UK has shown that there are a large number of applications either approved or in planning, totalling 2.8 GWe capacity.⁴⁶ Whilst not all of these plants are likely to be built, there is clearly scope for a significant further increase in capacity.
- Solar photovoltaic: There has been a very significant increase in solar capacity since 2005, with current capacity exceeding that forecast in the NREAPs.
- Biogas: Capacity has increased by a factor of five since 2005 and is on target to meet the 2020 NREAP target.
- Geothermal, concentrated solar power, bio-liquids, marine technologies: There has been a slight increase in capacity for these technologies, but attainment of the NREAP targets looks unlikely and all fall short of targets by a considerable amount.

⁴⁶ <http://www.biofuelwatch.org.uk/wp-content/maps/uk-biomass.html>

From these observations, it is likely that future increases in capacity will be focused on the following technologies:

- Wind (onshore and offshore)
- Solar voltaic
- Solid biomass
- Biogas

Taking these technologies in isolation, solid biomass accounted for 20 per cent in 2015, wind 52 per cent, solar 18 per cent and biogas 11 per cent. As a central estimate it is assumed that 20 per cent of additional renewable electricity capacity will come from biomass.

Total additional demand for renewables in electricity generation is described in Table 2 and Table 3, as follows for three scenarios:

- **Scenario 1: 40 Mtoe**, to move from projected renewable capacity in 2020 to the 27 per cent target for renewable energy. Assuming 20 per cent of capacity will be in the form of solid biomass equates to eight Mtoe. This is likely to be from wood as this appears to be the most popular choice amongst those developing new solid biomass schemes.
- **Scenario 2: 20,324 Mtoe** to move from the 24.3 per cent projected level of renewable capacity in 2030 to 27 per cent in 2030, with 4.065 Mtoe from solid biomass.
- **Scenario 3: 50,684 Mtoe** to move from the 24.3 per cent projected level of renewable capacity in 2030 to 30 per cent in 2030, with 10.137 Mtoe from solid biomass.

Recognising that pollutant damage per unit emission varies from country to country (reflecting population distribution), it is then necessary to look at capacity by country. This was done using information from the EEA renewable energy survey, taking data on solid biomass deployment for 2014 (Table 20). There will inevitably be some error in the way that capacity is distributed between countries, and this should be considered when assessing the results by country. However, so far as the total estimates of damage made below are concerned, it is to be expected that errors from assumption on plant distribution will cancel each other out to a possibly large extent given the number of countries involved.

Table 20. Solid biomass/electricity capacity for 2014 and 2020, with increase in capacity under three scenarios each providing 20 per cent of additional biomass capacity, by country.

	Current/forecast total capacity, ktoe		Increase in capacity, ktoe		
	2014	NREAP 2020	Scenario 1:2020-2030 projection	Scenario 2: 2030, 27% target	Scenario 3: 2030, 30% target
Total increase in renewables			40,000	20,324	50,684
Total for biomass	7,782	13,460	8,000	4,065	10,137
Austria	320	554	329	167	417
Belgium	226	391	233	118	295
Bulgaria	12	21	12	6	16
Croatia	4	7	4	2	6
Czechia	171	296	176	89	223
Cyprus	4	8	4	2	6
Denmark	331	572	340	173	431
Estonia	63	109	65	33	82
Finland	943	1,631	969	493	1,228
France	328	568	337	171	428
Germany	1,020	1,765	1,049	533	1,329
Greece	-	-	-	-	-
Hungary	146	253	150	76	191
Ireland	28	49	29	15	37
Italy	329	569	338	172	428
Latvia	27	47	28	14	36
Lithuania	25	44	26	13	33
Luxembourg	3	5	3	2	4
Malta	-	-	-	-	-
Netherlands	345	596	354	180	449
Poland	788	1,362	810	411	1,026
Portugal	218	376	224	114	283
Romania	59	102	61	31	77
Slovakia	81	139	83	42	105
Slovenia	11	19	11	6	14
Spain	328	568	338	172	428
Sweden	780	1,350	802	408	1,017
UK	1,191	2,060	1,224	622	1,551

These results can then be converted to MWe capacity, by applying the following factors:

- Convert ktoe to MWh, multiplying by a factor of 11,630
- Divide by a load factor assumed at 90 per cent
- Divide by hours per year, 8,760

Results are shown in Table 21.

Table 21. Increase in capacity, MWe, to meet the added demand for biomass

	Increase in capacity, MWe		
	Scenario 1: 2020-2030 projection	Scenario 2: 2030, 27% target	Scenario 3: 2030, 30% target
Austria	485	247	615
Belgium	343	174	435
Bulgaria	18	9	23
Croatia	7	3	8
Czechia	260	132	329
Cyprus	7	3	8
Denmark	501	255	635
Estonia	95	48	121
Finland	1,430	727	1,812
France	498	253	631
Germany	1,547	786	1,961
Greece	-	-	-
Hungary	222	113	281
Ireland	43	22	55
Italy	498	253	632
Latvia	42	21	53
Lithuania	38	19	48
Luxembourg	4	2	6
Malta	-	-	-
Netherlands	522	265	662
Poland	1,194	607	1,513
Portugal	330	168	418
Romania	89	45	113
Slovakia	122	62	155
Slovenia	16	8	21
Spain	498	253	631
Sweden	1,184	601	1,500
UK	1,806	918	2,289
Total	11,802	5,996	14,954

The quantity of wood required to meet the demand of six to 15 GWe can be calculated using information from the database of plants compiled in this research. Information on both electrical capacity and demand for biomass was available for 55 facilities. Taking the average estimate of 8,900 tonnes/MWe/year (noting that 90 per cent of values were in the range 5,000 – 15,000 t/MWe/year) provides a range for additional demand of between 54 and 134 million tonnes of biomass annually.

5.2 Quantifying emissions and damage

The next issue concerns the definition of the plants that provide this additional capacity, to permit quantification of emissions. For this we take the average emission per unit of electrical capacity for the plants listed in Table 14. The range around the average is large, as shown in Table 22. Most of the plants considered in Table 14 generate a significant amount of useful heat as well as electricity, though in this section we are primarily concerned with electricity generation alone. Analysis of the five plants that only generate electricity revealed that the average emission rate per MWe was almost identical to

the full sample, whilst ranges were a little truncated. Combining the capacity estimates in Table 21 with the emissions estimates from Table 22 provides the emissions estimates by country shown in Table 23.

Table 22. Average emission per MWe capacity for the biomass facilities listed in Table 14.

	NO _x , t/MWe	PM, t/MWe	SO ₂ , t/MWe
Average	5.7	0.21	2.6
Minimum	1.1	0.04	0.5
Maximum	12.6	0.45	5.9

Table 23. Emissions by country for the three scenarios of additional biomass use for electricity generation (tonnes).

	Scenario 1: 2020-2030			Scenario 2: 2030, 27% target			Scenario 3: 2030, 30% target		
	NO _x	PM	SO ₂	NO _x	PM	SO ₂	NO _x	PM	SO ₂
	5.70	0.21	2.60	5.70	0.21	2.60	5.70	0.21	2.60
Austria	2,766	102	1,262	1,406	52	641	3,505	129	1,599
Belgium	1,956	72	892	994	37	453	2,478	91	1,130
Bulgaria	103	4	47	52	2	24	131	5	60
Croatia	37	1	17	19	1	9	47	2	22
Czechia	1,481	55	675	752	28	343	1,876	69	856
Cyprus	38	1	17	19	1	9	48	2	22
Denmark	2,857	105	1,303	1,452	53	662	3,620	133	1,651
Estonia	543	20	248	276	10	126	688	25	314
Finland	8,151	300	3,718	4,142	153	1,889	10,328	381	4,711
France	2,838	105	1,294	1,442	53	658	3,596	132	1,640
Germany	8,821	325	4,023	4,482	165	2,044	11,177	412	5,098
Greece	-	-	-	-	-	-	-	-	-
Hungary	1,265	47	577	643	24	293	1,603	59	731
Ireland	245	9	112	125	5	57	311	11	142
Italy	2,841	105	1,296	1,444	53	659	3,600	133	1,642
Latvia	237	9	108	120	4	55	300	11	137
Lithuania	217	8	99	110	4	50	276	10	126
Luxembourg	25	1	12	13	0	6	32	1	15
Malta	-	-	-	-	-	-	-	-	-
Netherlands	2,978	110	1,358	1,513	56	690	3,774	139	1,721
Poland	6,808	251	3,105	3,459	127	1,578	8,627	318	3,935
Portugal	1,880	69	858	955	35	436	2,383	88	1,087
Romania	509	19	232	259	10	118	645	24	294
Slovakia	697	26	318	354	13	162	883	33	403
Slovenia	93	3	42	47	2	21	118	4	54
Spain	2,839	105	1,295	1,443	53	658	3,598	133	1,641
Sweden	6,746	249	3,077	3,428	126	1,564	8,548	315	3,899
UK	10,295	379	4,696	5,231	193	2,386	13,045	481	5,950
Total	67,269	2,478	30,684	34,179	1,259	15,591	85,236	3,140	38,880

Estimated health damage, based on the recommendations for quantification provided by the WHO HRAPIE study,¹⁹ and using the damage factors generated for the EEA (though adjusted for inflation, and accounting only for health impacts), are shown in Table 24, taking the conservative ‘median VOLY’ based estimate. Total damage associated with additional capacity required to meet the 27 per cent target

is equivalent to €372 million per year, or over €8 billion discounted over an assumed 30 year lifetime for new capacity. The figures for the 30 per cent target are €928 million and €20 billion.

Table 24. Health damage (€million) arising from additional emissions in each country

	Scenario 1: 2020-2030		Scenario 2: 2030, 27% target		Scenario 3: 2030, 30% target	
	1 year	30 year NPV	1 year	30 year NPV	1 year	30 year NPV
Austria	50.42	1,095.18	25.62	556.46	63.89	1,387.70
Belgium	32.17	698.74	16.34	355.03	40.76	885.38
Bulgaria	0.79	17.18	0.40	8.73	1.00	21.77
Croatia	0.43	9.39	0.22	4.77	0.55	11.89
Czechia	19.08	414.44	9.69	210.58	24.18	525.13
Cyprus	0.05	1.05	0.02	0.53	0.06	1.33
Denmark	24.41	530.22	12.40	269.40	30.93	671.84
Estonia	2.69	58.41	1.37	29.68	3.41	74.01
Finland	27.87	605.33	14.16	307.57	35.31	767.02
France	37.20	808.11	18.90	410.60	47.14	1,023.96
Germany	145.77	3,166.28	74.07	1,608.79	184.70	4,011.99
Greece	-	-	-	-	-	-
Hungary	17.08	371.02	8.68	188.52	21.64	470.12
Ireland	2.19	47.49	1.11	24.13	2.77	60.18
Italy	44.20	960.06	22.46	487.81	56.00	1,216.49
Latvia	1.70	36.99	0.87	18.79	2.16	46.87
Lithuania	1.88	40.77	0.95	20.72	2.38	51.67
Luxembourg	0.40	8.64	0.20	4.39	0.50	10.94
Malta	-	-	-	-	-	-
Netherlands	54.79	1,190.09	27.84	604.69	69.42	1,507.97
Poland	78.51	1,705.36	39.89	866.49	99.48	2,160.86
Portugal	8.75	189.97	4.44	96.52	11.08	240.71
Romania	6.56	142.41	3.33	72.36	8.31	180.45
Slovakia	8.31	180.40	4.22	91.66	10.52	228.59
Slovenia	1.55	33.76	0.79	17.15	1.97	42.77
Spain	17.49	379.90	8.89	193.02	22.16	481.37
Sweden	30.78	668.62	15.64	339.73	39.00	847.21
UK	116.96	2,540.45	59.43	1,290.80	148.20	3,219.00
Total	732	15,900	372	8,078	928	20,147

Table 25 and Table 26 show the health burden annually and over a 30 year period for each scenario. Both tables show mortality in the adult population from chronic exposure to fine particles expressed in terms of both deaths and life years lost: these are alternative expressions of the same impact.

Table 25. Annual health burden of additional biomass capacity under each scenario.

	Scenario 1: 2020-2030	Scenario 2: 2030, 27% target	Scenario 3: 2030, 30% target
	1 year	1 year	1 year
Total, € million	732	372	928
Chronic Mortality, life years lost	9,435	4,794	11,955
Chronic Mortality deaths	857	435	1,086
Infant Mortality (0-1yr)	4	2	5
Chronic Bronchitis in adults	720	366	913
Bronchitis in children aged 6 to 12	14,103	7,166	17,870
Respiratory Hospital Admissions	319	162	404
Cardiac Hospital Admissions	125	63	158
Restricted Activity Days	1,098,311	558,052	1,391,669
Asthma symptom days in children	31,903	16,210	40,424
Lost working days	152,490	77,480	193,220

Table 26. Health burden of additional biomass capacity extrapolated to 30 year plant lifetime under each scenario.

	Scenario 1: 2020-2030	Scenario 2: 2030, 27% target	Scenario 3: 2030, 30% target
	30 year	30 year	30 year
Total, € million	15,900	8,079	20,147
Chronic Mortality, life years lost	283,053	143,819	358,657
Chronic Mortality deaths	25,703	13,059	32,568
Infant Mortality (0-1yr)	126	64	160
Chronic Bronchitis in adults	21,614	10,982	27,387
Bronchitis in children aged 6 to 12	423,093	214,974	536,101
Respiratory Hospital Admissions	9,572	4,864	12,129
Cardiac Hospital Admissions	3,749	1,905	4,750
Restricted Activity Days	32,949,317	16,741,548	41,750,080
Asthma symptom days in children	957,088	486,297	1,212,726
Lost working days	4,574,702	2,324,406	5,796,605

The results demonstrate that the health impacts associated with further biomass capacity are substantial, with a loss of life expectancy across the population of 4,800 to 12,000 years, equivalent to 435 to 1,100 deaths for emissions associated with operation of additional capacity for a period of one year (the ranges reflecting the different scenarios). Emissions are also linked to the development of long term disease in the adult population, with estimates of an additional 366 to 913 cases of chronic bronchitis annually. Bronchitis rates in children are also anticipated to increase, by 7,000 to 18,000 cases per year.⁴⁷ There are an estimated additional 220 to 560 hospital admissions annually, and then an increase in lower levels of disease, leading to restrictions on daily activities, including lost working days. Impacts will accumulate year on year for as long as the additional biomass capacity continues to operate.

⁴⁷ A distinction must be drawn between bronchitis in adults and children. For adults, the disease is long-lasting, possibly permanent. For children, however, illness lasts for around 2 weeks. Valuations differ between the two effects to reflect this difference.

5.3 Uncertainties

5.3.1 Key uncertainties

The key uncertainties affecting this analysis concern:

- The extent to which woody biomass is used to increase renewables capacity for electricity generation
- Emissions associated with the increase in biomass capacity
- The exclusion of some health impacts from the analysis
- The exclusion of non-health impacts from the analysis
- Valuation data

Solid biomass, most of which takes the form of wood, accounted for 20 per cent of renewable electricity capacity in 2015 for the technologies (wind, solid biomass, solar photovoltaic and biogas) where further capacity increases seem most likely based on current trends. There is clearly uncertainty around this figure. A range of +/-10 per cent seems reasonable, though perhaps conservative at the upper end if additional capacity comes in through the use of large power stations originally designed to burn coal. Several examples of these power stations, with generating capacities in the order of one GW and more, have been identified in this report. The UK's Drax power station provides a well-documented case that demonstrates that such plants can be developed using imported wood fuel, with supplies of several million tonnes per year imported from the southern US states. On this basis, a more realistic range could be 10-40 per cent around the best estimate of 20 per cent of additional capacity supplied by solid biomass.

Uncertainty in emissions data arises for several reasons:

- Type of installation (whether new-build biomass, or converted from old coal)
- Adoption of CHP, displacing other heating options (though noting that additional CHP demand may be limited)
- Type of material used as fuel
- Emission controls in place
- Load factors for individual plants
- 'Head-room' between likely emissions and permit conditions

For these reasons the preferred option here was to take emissions data from existing plants, for which information is publicly available. Even then there is a problem, as emissions data are not available for all plants, and for those facilities for which some information has been published, only for some pollutants. Table 22 demonstrated a variation factor of 10 between best and worst performing plants for emissions per MWe installed. Actual uncertainty is likely lower: plants at the lower end of the range may be operating at low load factors and plants at the upper end may be operating with limited emission controls. A range around the best estimate of +/-50 per cent is adopted here.

A number of health impacts have not been quantified in this analysis. WHO under the HRAPIE study¹⁹ includes functions for NO₂ that would be relevant here, but are not quantified given uncertainty in the way that exposure should be modelled. The report by the RCP and of Child Health and Paediatrics in the UK²⁰ highlights links between air pollution and a number of chronic health conditions that have been identified in the epidemiological literature, with diabetes, obesity and dementia. There is currently limited literature on these impacts, and a variable mechanistic understanding of the link to air pollution. If the links are proven true, it is possible that the inclusion of these impacts would have a significant effect on damage estimates. An arbitrary estimate of 10 per cent additional damage is assumed here for the purpose of illustration: the actual underestimate based on the methods used here seems unlikely to be lower, and possibly significantly higher than this.

With respect to the valuation of the quantified impacts, the figures shown in the tables represent a conservative position. Adopting the upper end of the ranges used by the EEA would increase monetised

damage estimates by a factor of 2.8. Adoption of the value of statistical life derived from an extensive meta-analysis by the OECD⁴¹ would increase estimates further, by around 30 per cent. Even this figure is conservative compared to those used by the United States Environmental Protection Agency (USEPA).

The exclusion of non-health impacts may have only a limited effect on total monetised estimates of damage, perhaps in the order of 10 per cent based on current knowledge of the economics of damage to buildings, crops, forests and ecosystems.

5.3.2 Conclusions on overestimation or underestimation of impacts

An indication of the effect of these uncertainties on the outcome of the analysis is provided in Table 27. Taking a low estimate of capacity and of emission rates reduces total damage by a factor of two to €167 million/year. Taking the upper end of the ranges increases damage by a factor of 10 to €3.8 billion/year. Either way, the additional damage associated with an increased capacity of solid biomass combustion is a considerable additional burden on society and is worthy of consideration in assessment of the revised directive.

Table 27. Indicative uncertainty analysis. Units: € million/year

Factor	Uncertainty factor	Current estimate	Low	High
Applying each uncertainty factor individually				
Capacity	10%-40%	372	186	744
Emissions	+/-50%	372	186	558
Exclusion of health impacts	+10%	372	409	
Exclusion of non-health impacts	+10%	372	409	
Valuation	Current estimate to factor 2.8 increase	372	372	1,042
Combined			167	3,781

6 Conclusions

The use of biomass for power generation, and in particular, wood, could expand significantly following the revision of the Renewable Energy Directive. Targets for renewable energy as a share of final energy use are set to increase from a projected 24.3 per cent in 2030 to 27 per cent under the Commission's proposal, and 30 per cent under the Parliament's (Section , acknowledging that the Parliament may vote on a higher target still, of 35 per cent). Biomass already makes a major contribution to heating and cooling and is making an increasing contribution to electricity generation, with the advantage over several other renewable energy technologies that it can be phased to meet demand in a way that intermittent technologies like solar or wind, as examples, currently cannot, at least prior to the introduction of improved storage facilities.

The purpose of this report is not to question the need for a high level of ambition for renewables, but to make clear that an increase in use of biomass combustion to meet this ambition would have a significant impact on human health, an impact that is not reflected in the Impact Assessment on the proposals made.

Whilst this study has acknowledged questions concerning the use of biomass as a fuel in relation to climate change, its main focus is on the health impacts of air pollutants emitted from the burning of woody biomass in particular, operating at the local and regional scale.⁴⁸ Several pollutants linked to biomass combustion are recognised as harmful to health through effects on (Section 2.2.1):

- Development of cancer
- Cardiac and respiratory disease, including long-term conditions such as chronic bronchitis
- Exacerbation of asthma
- Low level impacts that lead to restricted activity levels, including a loss of working days

There is little scope for an increase in the use of biomass in the domestic sector (Section 3.1). It already accounts for a large share of renewable energy in the sector, and overall energy demand in the sector is anticipated to fall in coming years through improved levels of energy efficiency. The difficulty in meeting air quality legislation will also have an impact, with local authorities taking action to further enforce smoke control areas. However, the maintenance of a sizeable level of biomass combustion will continue to have impacts for the foreseeable future. Sigsgaard et al¹⁰ estimate that emissions from domestic biomass use currently account for 40,000 deaths annually across the EU28. This figure is used in Section 3.4 to also calculate impacts on chronic bronchitis and hospital admissions etc. The final economic value is estimated to be between €33 and 114 billion annually. This impact will persist for as long as biomass continues to be burned.

With respect to industrial use for power generation, a sector where capacity is set to increase, the study has quantified the damage associated with three scenarios:

- **Scenario 1: 40 Mtoe additional capacity required**, to move from projected renewable capacity in 2020 to the 27 per cent target for renewable energy. Assuming 20 per cent of capacity will be in the form of solid biomass (equating to 8 Mtoe).
- **Scenario 2: 20,324 Mtoe additional capacity required**, to move from the 24.3 per cent projected level of renewable capacity in 2030 to 27 per cent in 2030, with 4.065 Mtoe from solid biomass.
- **Scenario 3: 50,684 Mtoe additional capacity required**, to move from the 24.3 per cent projected level of renewable capacity in 2030 to 30 per cent in 2030, with 10.137 Mtoe from solid biomass.

The scenarios considered here assume that biomass will contribute 20 per cent of the added demand for renewable generation. This is higher than the forecast contribution in 2020 (12.7 per cent), but as shown in Section 5.1, is not unreasonable given that expansion of hydropower (which currently accounts for 30

⁴⁸ Potential effects via impacts on the role of forests as a sink for air pollution are not considered.

per cent of renewable generation) is unlikely given trends over the last 10 years, and limited penetration of several other technologies (geothermal, marine, etc.)

Section 4.1 provides a review of existing biomass facilities to assess the types of plant being developed in terms of size and provision of heat as well as electricity, fuels used, etc. An important development is traditional coal fired generators' interest in converting existing plants to burn biomass. Not all attempts at conversion have proved successful, with some plants closing down already. However, there are several notable examples where conversion has been successful. The size of these plants changes the market for biomass as a fuel, moving away from locally sourced materials to developing international markets.

Impacts have been quantified using the same methods used for quantification of damage by the EEA, which in turn are based on the methods used by the European Commission in assessment of legislation on air quality (Section 4.2). Headline results are shown in Table 28 (extracted from Table 25 and Table 26) for effects on mortality and the economic equivalent of quantified health impacts. Both are shown for one year and aggregated up to an assumed 30 year operating life for the additional capacity. These results demonstrate that the health effects of increased biomass capacity for power generation are likely to be substantial, although there is a strong tendency for conservatism in the methods used (see Section 5.3).

Table 28. Headline results for scenarios of increased biomass use for electricity generation

	Scenario 1: 2020-2030	Scenario 2: 2030, 27% target	Scenario 3: 2030, 30% target
	1 year	1 year	1 year
Total, € million/year	732	372	928
Chronic Mortality, life years lost	9,435	4,794	11,955
Chronic Mortality deaths	857	435	1,086
	30 year	30 year	30 year
Total, € million (NPV)	15,900	8,079	20,147
Chronic Mortality, life years lost	283,053	143,819	358,657
Chronic Mortality deaths	25,703	13,059	32,568

Section 2.3 shows that the Impact Assessment for the revised Directive does not provide any quantification of the air quality impacts of additional biomass capacity, on the grounds that:

Given the fact that air pollution from biomass is specifically addressed through other EU measures and regulations, it is not considered appropriate to set specific requirements in the context of this policy initiative.

However, in order to develop “no-regret” policies on the development of renewables, it is necessary that the impacts of biomass burning are considered in the development of both the revised Directive and action plans for meeting the requirements of the Directive, including:

1. The burning of biomass, even under controlled conditions, leads to significant emissions of air pollutants that are harmful to both health and the environment.
2. There are no thresholds for exposure to fine particles, and several other pollutants from the burning of biomass.
3. Even at low concentrations, the pollutants associated with biomass burning can cause significant harm to the population.
4. There is a compliance gap with legislation on emission controls and ambient air pollutant concentrations (Section 2.2.4). Adding further to air pollution will widen this gap and make it more difficult, and more expensive to meet regulated levels.

With these issues in mind, the promotion of any combustion technology runs counter to efforts to improve air quality, and these concerns are a material consideration to the revision of the Directive.

Finally, in the context of the revision of the Directive, it is not appropriate to compare the air pollution performance of biomass with the use of fossil fuels. In other words, the harm done via air pollutant emissions from burning wood should not be quantified net of a fossil fuel alternative. Biomass is not competing against fossil fuels to fill the gap between current and forecast levels of renewable power generation: it is competing against other renewable technologies, which may offer a solution with substantially lower external costs.



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